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UNITED STATES BUREAU OF MINES
Scott Turner, Director

INFORMATION CIRCULAR

EXPLOSIONS IN VIRGINIA COAL MINES

1839 TO 1933

BY

Joseph F. Davies and H. B. Humphrey

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By Joseph F. Davies[2] and H. B. Humphrey[3]

PURPOSE OF THIS REPORT

Analysis of past experience is one of the best guides to improvement, particularly in regard to the prevention of accidents; by this means a relatively true picture of the causes of accidents may be drawn, the need of preventive measures judged, and their effectiveness determined. Explosions are entirely preventable in mining, yet they ranked third among the causes of fatal accidents in the United States during the 10 years ended December 31, 1932, and caused 16.1 percent of the fatal accidents in bituminous-coal mines during that period.

Virginia held eighth place among the States in coal production in 1932. Her mines had an enviable record, with no explosions for several years before 1932; during the first 9 months of that year, however, they had 3 explosion disasters in a period when none occurred in the rest of the coal mines of the United States. This circular gives available information on the explosions in the coal mines of Virginia as far back as 1839. Causes are summarized, the pertinent factors leading to the disasters are detailed and grouped, and the success or lack of protective measures noted.

Data collected and published by the United States Bureau of Mines were used in compiling the tables used in this report; in addition, the Virginia Department of Labor and Industry, through its division of mines, assisted in locating published records. The operating companies in the State freely gave information on explosion occurrences at their properties. Because of the long period of mining and the fact that only summarized tables of fatalities are given in the annual reports, even today, some cases may have been undiscovered; their omission, however, will not materially affect the resulting conclusions.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6766".
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HISTORICAL SUMMARY

The first coal mined in the United States is said to have been along the James River in the Richmond Basin near Richmond, Va. The date usually given is 1750, although some accounts state that this coal was used as early as 1700. The first record of production is for 1822, when 54,000 tons were mined in one year, but after the "War of the 60's" mining declined in this field; although some revival was attempted after 1900, coal production was discontinued in a few years, although great coal reserves remain.

The Pocahontas field was opened in 1822, when the Norfolk & Western Railway was built, and has been an increasingly large producer. Semianthracites[3a] were mined on a small scale locally in Pulaski and Montgomery Counties from before the Civil War until about 1895; since that time coal has been shipped constantly. The coal fields in Wise and adjoining counties in the Southwest district were opened in 1891 with the building of the Norfolk & Western and the Louisville & Nashville Railroads to Norton.

Thus, by 1894 over a million tons per year were being mined in the State and 2 million by 1899. Production doubled every few years and reached 10 million tons in 1917. The highest figure was 14 million tons, produced in 1926. The output for 1932 was 7,692,000 tons.

The periods of numerous explosions in any of these fields came when the mines were so extended that gas and dust accumulated. In the Richmond Basin this period began when depths were reached that required real ventilation and lasted until work was stopped and the mines filled with water. Likewise, in the semianthracite field of Pulaski and Montgomery Counties explosive gas did not prove troublesome in early years before the mines reached considerable depth and extent.

Drift mines in the Pocahontas and Southwest Virginia districts have had not only local ignitions but also violent explosions in both large and small mines since they were opened.

FATALITIES

A remarkable feature of Virginia mines is the rarity of small explosions resulting in single fatalities; 1 explosion killed 112 men; 2 others killed 55 and 69; 8 had 10 to 40 fatalities each; and the other 12, 2 to 9 fatalities each. This is an abnormally large number of fatalities for the number of explosions involved compared with the experience of other States and may be due to the fact that no record is available of less disastrous explosions which probably occurred in the earlier years, many of which may have resulted in single fatalities. The following tabulation of explosions and deaths for periods of years may prove illuminating:

[3a] Otherwise known as Virginia hard coal or anthracite mined in Virginia.

TABLE 1. - Explosions and deaths, by periods

Period	Explosions	No. killed	Average no. killed per explosion
1839 to 1870, 31 years	7	217	31
1871 to 1900, 29 years	5	162	27
1901 to 1930, 29 years	14	98	7
1931	0	0	0
1932	3	54	18
Totals and averages	29	531	18

Table 2 lists the explosions causing fatalities or indicating violence with no accompanying fatalities. Table 3 lists many nonfatal occurrences that might be called local explosions or ignitions. The list is representative of this type of explosions; although not complete, as many such explosives are never recorded, it includes enough of them to show the many potential disasters that were escaped, in most cases by fortunate chance only. In these 42 local ignitions 71 men were more or less seriously burned or injured. Of the 29 explosions given in table 2, resulting in 531 fatalities, 2 caused no deaths and 2 others only 1 death each.

TABLE 2. - Gas and dust explosions in Virginia coal mines with resultant fatalities or violence, 1839 - 1933

Case	Date	Mine	County	Type of mine	Daily ton-nage	Men		Explosion			Cause of accumu-lation	Source of ignition	Other factors	Possible means of prevention	Killed	Injured	Escaped	Yearly total killed
						Average em-ployed	In mine	Type	Ex-tent	Limited by								
1	1839: Mar. 18	Black Heath	Chesterfield	Slope, gassy	85	60	-	Gas, dust	Vio-lent	Going to sur-face	Door left open over Sunday.	Open light.	No inspec-tion be-fore Mon-day shift.	Flame safe-ty lamp and inspec-tion	40	3	-	40
2	1850	Cox's pit, Clover Hill	do	do	-	-	-	Gas	-	-	-	Probably open light.	-	Probably flame safe-ty lamps and inspec-tion.	7	-	-	7
3	1854: May 15	Chesterfield		do	-	-	20	do	-	-	Unventi-lated old workings.	Open light.	-	Ventilation and inspec-tion, flame safety lamps.	20	0	0	20
4	1855: Mar. 19	Midlothian	-	do	-	-		Gas, dust	Vio-lent	Expan-sion	Blast re-leased gas from old work-ings.	Blasting.	-	Ventilation, inspection, supervision, drill holes ahead.	55	5	-	
5	1859: Apr. 13	Bright Hope	Chesterfield	do	-	-	-	Gas	Local but strong	-	Open door, gas gath-ered in heading.	Open light.	Aided by kegs of powder.	Supervision, inspection, flame safe-ty lamps, careful storage of explosives.	9	1	-	9
6	1863	Raccoon	do	-	-	-	-	do	-	-	Soldiers, stripping mine.	do	-	Ventilation, inspection, supervision	17	-	-	17
7	1867: Apr. 3	Bright Hope	do	Shaft, gassy	-	-	69	Gas, dust	Vio-lent	-	Door re-moved.	do	Neglect of gas-men.	Supervision, ventilation, inspection.	69	0	0	69

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TABLE 2.- Gas and dust explosions in Virginia coal mines with resultant fatalities or violence, 1839 - 1933 -- Continued

Case	Date	Mine	County	Type of mine	Daily tonnage	Men		Explosion			Cause of accumulation	Source of ignition	Other factors	Possible means of prevention	Killed	Injured	Escaped	Yearly total killed
						Average employed	In mine	Type	Extent	Limited by								
8	1875	Raccoon pit	Chesterfield	Slope, gassy	-	-	3	Gas	Local	Small amount.	Unventilated working place. Supt. and 2 gasmen.	Open light.	Used both Davy and open lights.	Exclude open lights.	3	0	0	3
9	1876: May 20	Midlothian	-	Shaft, gassy	-	-	10	do	Violent	Expansion	Inadequate ventilation.	do	Foreman investigating reported gas with open light.	Ventilation, inspection, flame safety lamps.	8	2	0	8
10	1882: Feb. 3	do	-	do	-	-	32	Gas dust	do	-	Sealed fire area.	do	No explanation given.	Supervision, and flame safety lamps.	32	0	0	32
11	1884: Mar.13	Laurel	Tazewell	Drift, non-gassy	-	500	155	Dust	do	-	Blast blocked drifts. Main doors open.	Blasting.	Mine dry and dusty.	Safer blasting ventilation, supervision, dust removal, wetting.	112	-	-	112
12	1900: May 10	Lee	Wise	do	450	100	5	do	do	Expansion	Very dusty, ineffective sprinkling; 2 rescuers killed.	do	20 sticks-open shot on rock.	Safer blasting, dust removal, watering.	7	0	0	7

TABLE 2. – Gas and dust explosions in Virginia coal mines with resultant fatalities or violence, 1839 - 1933 -- Continued

Case	Date	Mine	County	Type of mine	Daily tonnage	Men		Explosion			Cause of accumulation	Source of ignition	Other factors	Possible means of prevention	Killed	Injured	Escaped	Yearly total killed
						Average employed	In mine	Type	Extent	Limited by								
13	1901: Nov. 14	Pocahontas	Tazewell	Drift, non-gassy	–	–	–	Gas	Violent	–	Fire deranged ventilation ignited accumulated gas.	Mine fire.	–	–	9	20		17
13A	Nov. 22	do	do	–	–	–	8	do	–	–	Party went in to inspect after explosion of Nov. 14. Killed by CO.	do	–	Ventilation and test for CO	8	0	0	
14	1906: Oct. 3	do	do	Drift, gassy	–	–	80	Gas, dust	Strong	Expansion and wet sections	Black blasting powder (solid).	Blown-out shot.	Shifts changing 34 plus 2 in recovery.	Safer blasting, dust	36	0		36
15	1907: Mar. 16	Greeno	Wise	Slope, gassy	100	30	10	do	–	Expansion,	Changing from furnace to fan. Ventilation interrupted.	Open light.	Section marked out. Driver went in to get coal.	Closed lights, supervision, clear mine before men enter, water.	6	2	2	6

TABLE 2. - Gas and dust explosions in Virginia coal mines with resultant fatalities or violence,
1839 - 1933 -- Continued

Case	Date	Mine	County	Type of mine	Daily ton-nage	Men		Explosion			Cause of accumu-lation	Source of ignition	Other factors	Possible means of prevention	Killed	Injured	Escaped	Yearly total killed
						Average employed	In mine	Type	Ex-tent	Limited by								
16	1909: Jan.	Carbon Hill	Chesterfield	Slope, gassy	-	-	-	Dust	-	-	Probably solid shooting & black blasting powder.	Blasting.	Probably tamped with coal dust.	Safer blasting, water, dust removal.	6	5		6
17	1910: Dec. 14	Greeno	Wise	do	50	15	12	Gas, dust	Strong	Expansion, inert dust on entries, dampness.	Gas forced down on lights by brushing with air hose.	Open light.	No State inspection service.	Closed lights ventilation, inspection, water.	8	1	3	8
18	1911: Jan. 21	Carbon Hill	Chesterfield	do	150	90	-	do	-	Expansion, water	Miner crossed danger board into room marked off.	do	-	Closed lights, supervision, ventilation.	7	6		7
19	1912: June 19	do	do	do	150	90	-	Gas	-	do	Man passed danger sign into gas in gangway face with open light.	do	-	do	2	8		
20	July 16	do	do	do	150	90	10	Gas, dust	Small	Watering, washing, steam, sprinkling.	Lit gas while splitting fuse with match. dust from 1st hole ignited.	Open flame	Inadequate ventilation, inspection, and supervision.	Ventilation, inspection, permissible blasting.	8	1	1	10

TABLE 2. – Gas and dust explosions in Virginia coal mines with resultant fatalities or violence, 1839 – 1933 –– Continued

Case	Date	Mine	County	Type of mine	Daily tonnage	Men		Explosion			Cause of accumulation	Source of ignition	Other factors	Possible means of prevention	Killed	Injured	Escaped	Yearly total killed
						Average employed	In mine	Type	Extent	Limited by								
21	1915: Aug. 15	Parrott	Pulaski	Slope, gassy	–	–	–	Gas	Local	Small amount	Fireboss fanning out gas. Davy lamp.	Open light.	Man came into crosscut with open light.	Ventilation, supervision, closed lights.	1	0	1	1
22	1918: Jan. 5	Reed Creek	Lee	Drift, non-gassy	40	10	7	Dust	Strong	Inert dust, expansion	Solid shooting 2 or 3 blownout shots.	Blown-out shot.	Black blasting powder, "bug" dust tamp.	Cut coal, permissible blasting, water	4	0	3	5
23	July 14	Roda No. 3	Wise	Drift, gassy	1,000	250	–	Gas	do	Expansion, water pool	At face inby last x-cut. Fireboss.	Open light.	Safety lamp on belt unlit.	Closed lights, supervision.	1	0	0	
24	1925: June 9	Linden No.2	do	do	–	–	–	do	Local	Expansion, pillar workings	A second fall pushed gas from gob over light.	do	Some dust burned.	Ventilation, inspection, closed lights.	0	3	0	0
25	1927: Mar. 24	Splashdam No. 5	Dickenson	do	500	100	10	do	Small	Expansion	Air short-circuited in starting a new wall face.	do	Men examining area.	Closed lights, venvilation, inspection.	0	8	2	0
26	1928: Aug. 25	Great Valley	Pulaski	Slope, gassy	800	70	2	do	Local	Inert dust	Fan stopped until men entered. No inspection. Active section on return.	Electric arc.	Put current on battery	Electric equipment on intake, continuous ventilation, inspection.	2	0	0	2

TABLE 2. - Gas and dust explosions in Virginia coal mines with resultant fatalities or violence, 1839 - 1933 -- Concluded

Case	Date	Mine	County	Type of mine	Daily ton-nage	Men		Explosion			Cause of accumu-lation	Source of ignition	Other factors	Possible means of prevention	Killed	Injured	Escaped	Yearly total killed
						Average employed	In mine	Type	Ex-tent	Limited by								
27	1932: Jan. 18	Parrott	Pulaski	Slope, gassy	320	117	18	Gas, dust	Strong	Partly inert dust	Inadequate ventilation and inspection.	Smoking.	Propagated by gas and dust mixture.	Ventilation, inspection, supervision.	6	0	12	54
28	Feb. 27	Boissevain	Tazewell	Shaft, non-gassy	2,200	300	42	Dust	Violent	Wet section, expansion	Dust raised by 4 bottom holes ignited by 4 overcharged top holes.	Blown-out shots.	Stemmed with bug dust.	Permissible blasting, rock-dust.	38	0	0	
29	June 13	Splashdam No. 6	Dickenson	Drift, gassy	300	80	10	Gas, dust	do	Water hole, expansion	Fan started as men went in.	Open light.	No inspection.	Ventilation, inspection, closed lights, rock-dust.	10	0	0	
	Total														531	69	22	531

TABLE 3. - Gas and dust nonfatal ignitions, Virginia

Date	Field	Type of mine	Cause	Source of ignition	Injured
1850	Richmond	Gassy	Poor ventilation and inspection	Open light	1 miner
1860	do	do	do	do	do
1872	do	do	Strong feeder	do	1 superintendent
1872	do	do	do	do	do
1883	Pocahontas	Non-gassy	Dry, dusty, black blasting powder, dust, flame, and keg of powder	Blown-out shot	2 miners
1903	Anthracite	Gassy	Clearing gas with pipe and steam jet	Open light	1 foreman
1904	do	do	Entered idle unventilated room, no inspection	do	1 foreman 1 fireboss
1910	Richmond	do	Overcharged hole in rock, black blasting powder and dust	Blown-out shot	10 men
1910	Southwest	do	Clearing gas from roof cavity with compressed air	Open light	2 miners
1914	do	do	Cut into roof feeder, miner returned after shot	do	1 miner
1916	do	do	Surveyors in old works, poor ventilation, no inspection	do	2 engineers
1916	do	do	Cut into old workings containing CH_4, CO_2, and air	do	1 miner
1916	do	do	Went over slate fall into idle working	do	1 trackman
1916	do	do	Went back into face shortly after cutting	do	2 miners
1917	Anthracite	do	Put head in hole, x-cut air course to heading	do	1 miner
1918	do	do	Cutting air course, poor ventilation, raised light too high off floor.	do	do
1918	do	do	Fanning out gas over open light	do	5 miners
1922	Southwest	do	Poorly ventilated face, faulty or no inspection	do	1 miner
1923	Anthracite	do	Fanned gas back on lamp	do	do
1923	Southwest	do	Assistant foreman passed through curtain, had safety lamp, but was smoking	Smoking	1 section foreman
1924	do	do	Small pocket. (Before they used closed lights)	Open light	1 miner
1924	do	do	Drilling in heading, poor ventilation	Electric drill	do
1924	do	do	Drilling in heading, went back too soon after shooting	do	2 miners

TABLE 3. - Gas and dust nonfatal ignitions, Virginia--Continued

Date	Field	Type of mine	Cause	Source of ignition	Injured
1924	Southwest	Gassy	Drilling in air course heading	Electric drill	1 miner
1925	do	do	Cut into old borehole	Open light	2 miners
1925	do	do	Slate fall in "robbed" area drove out gas over open light	do	3 miners
1925	Anthracite	do	Brattice shot down, not replaced until gas gathered	do	1 miner
1925	do	do	Airway blocked by coal shot down	do	do
1925	Southwest	do	Gas near roof over fall, foreman examining	do	1 foreman
1926	Anthracite	do	Examining rise room, opened safety lamp to relight	do	1 fireboss
1927	do	do	No inspection at face heading	do	1 miner
1927	Southwest	do	Loading coal	do	do
1927	do	do	Fanned gas back over lamp, door left open	do	do
1923	Anthracite	do	Examining high cavity, opened safety lamp to relight	do	1 fireboss
1928	do	do	Fixing machine, poor ventilation and inspection	Blown-out shot	4 machinemen
1930	do	do	In roof-fall cavity, faulty or no inspection	Open light	1 miner
1931	Southwest	do	Engineer went past wing curtain in air course	do	1 engineer
1931	Anthracite	do	Shooting on solid, dynamite and dust	Blown-out shot	4 miners
1932	Southwest	do	Foreman inspecting for reported gas with open light	Open light	1 foreman
1932	Anthracite	do	West up to face after shooting without extending curtain	do	2 brattice-men
1933	do	do	Looked into shot holes with open light	do	1 miner
1933	do	do	do	do	do

Table 4 shows the explosions listed in table 2, arranged according to occurrence by coal fields:

TABLE 4. - Occurrence of explosions by coal fields

Field	Period covered	No. of explosions	No. killed	Average no. killed per explosion
Richmond Basin	1839-1912	14	283	20.2
Pocahontas	1884-1932	4	203	50.8
Pulaski	1916-1932	3	9	3.0
Southwest	1900-1932	8	36	4.5
Totals and averages	-	29	531	18

In the Richmond Basin the earliest reported explosion was that in 1839. Reference has been found to a possible explosion in 1817 and others in 1841 and 1844, accounts of which, however, were not discovered. The list of explosions in this area would, no doubt, have been larger had the mines not been virtually idle from about 1890 until the small revival about 1906.

The record of the Pocahontas field in Virginia is one of heavy disasters at rather long intervals. The Pulaski or semianthracite district has a light record as regards fatal explosions, probably because of the nature of the coal dust. Nonfatal ignitions have been numerous.

The record of the Southwest field indicates a more or less average performance compared with that of neighboring fields in other States.

In the 29 explosions with fatalities or violence listed for the State only 69 men escaped with injuries; these escaped death in 13 of the explosions, and in the other 16 no nonfatal injuries occurred in so far as the records indicate. As a whole, the list of those who escaped uninjured is too incomplete to permit conclusions to be drawn; however, in the last 10 years 62 men were killed in explosions in Virginia coal mines, and 18 escaped uninjured, 12 of these being in an explosion in a semianthracite mine.

Table 5 presents the fatality rates from gas and dust explosions per million man-hours of underground exposure. The rates are erratic because of the irregular nature of these disasters; they show no particular trend. The production and employment totals are relatively too small for generalization on this type of accident.

TABLE 5. - Explosion fatality rates and percentage of total, by periods

Period	Fatalities per million--			Percentage of total number killed--	
	Tons,	Man-hours (inside)			
	Va.	Va.	U.S.	Va.	U.S.
1901 - 10 10 years	1.75	0.60	- -	20.9 [1]	20.0
1911 - 20 10 years	.26	.12	0.11	4.9	12.4
1921 - 25 5 years	.00	.00	.35	.0	14.8
1926 - 30 5 years	.03	.02	.31	.9	12.5
1931 - 1 year	.00	.00	.13	.0	6.0
1932 1 year	7.02	6.00	.25	76.1	14.3
1901 - 32	- -	- -	- -	11.4	14.0

[1] 1902 - 05, estimated.

CAUSES OF EXPLOSIONS

Three fourths of the explosions with resultant fatalities or violence were charged to open lights, including 1 by a mine fire and 1 by smoking. About one fourth were caused by blasting, and 1 explosion was ignited by an electric arc.

TABLE 6. - Causes of explosions and ignitions in Virginia coal mines, 1839-1932

Explosions with resultant fatalities or violence listed in table 2			Ignitions without fatalities or violence listed in table 3		
Causes	Explosions	Percent	Causes	Ignitions	Percent
Open lights or flames	21	73	Open lights or flames	35	83
Blasting	7	24	Blown-out shots	4	10
Electric arc	1	3	Electric arc	3	7
Total	29	100	Total	42	100

Of the 42 nonfatal ignitions 35 were caused by open lights, including at least 1 by smoking. Three, caused by electric drills of a nonpermissible type, burned at least 4 men in 1 mine; these drills were subsequently discarded.

Open lights.- Of the 21 fatal or violent explosions caused by open lights, 12 occurred in the Richmond Basin, 6 in the Southwestern field, 2 in the Pulaski semianthracite mines, and 1 by a fire in the Pocahontas field. In the past 10 years, 4 of the 6 explosions listed for the coal mines of Virginia were charged to open lights or smoking.

Blasting.- Two explosions in the Richmond Basin were charged to blasting; 3 in the Pocahontas field were caused by blown-out shots; and 2 in the Southwestern area were charged to the same cause. In 3 cases shooting was done on the solid, and black blasting powder was used; in another a heavy, open charge of dynamite was exploded on a large piece of rock. In most of these cases (probably in all of them) the charge was stemmed with coal dust.

TYPES OF EXPLOSIONS

Designating mines in table 2 as gassy or nongassy is based on the actual presence or absence of gas, according to standards expressed in Mine Safety Board Decision 3. (See p. 20)

TABLE 7. - Types of explosions that have occurred in coal mines of Virginia

Kind of mine	Explosions with resultant fatalities or violence			
	Gas	Dust	Gas and dust	Total
Nongassy	0	4	0	4
Gassy	13	1	11	25
All mines	13	5	11	29
Fatalities	87	167	277	531

The 29 explosions described in table 2 are summarized in table 7 to show the number that occurred in gassy and nongassy mines; they are grouped according to the type of explosion, as gas, dust, or gas and dust in combination.

Seven of the explosions charged to gas alone occurred in the mines of the Richmond Basin and caused 66 of the 87 fatalities. Of the remaining cases, 1 was in the Pocahontas field, resulting in 17 deaths, and 2 were in the Pulaski mines, with 3 deaths. The other 3 were in mines of the Southwest district, with only 1 death resulting. Gas explosions caused an average of nearly 7 fatalities apiece.

Dust explosions caused a heavy loss of life in nongassy mines. Two in the Pocahontas field resulted in 150 deaths. Two others were in the Southwest district and the other in a gassy mine in the Richmond Basin. All 5 of these explosions were initiated by blasting or using explosives or by practices that had been proved unsafe. Dust explosions averaged about 33 fatalities each.

The 11 explosions involving both gas and dust caused 277 fatalities, or about 25 fatalities per explosion. Six were recorded in the Richmond Basin, 3 in the Southwest, and 1 each in the Pocahontas and Pulaski fields.

PREVENTION OF EXPLOSIONS IN VIRGINIA COAL MINES

Even in the early period when frequent and disastrous explosions were occurring in the Richmond Basin, methods and means were at hand to prevent or greatly reduce the possibility of their occurrence. Customary practice and the belief that adoption of protective measures was unwarranted seem to have been the main reasons for not making use of the knowledge and means developed by past experience. On the other hand, there is no doubt that then, as now, some officials in responsible charge of the mining operations were not awaro of the dangers confronting them and were shocked and surprised when disasters occurred. For at least 15 or 20 years means have been as readily available for preventing explosions in Virginia as in any other State in the Union.

Recommendations to prevent recurrence of similar explosions were made in reports on these explosions by engineers of the United States Bureau of Mines and other investigating bodies. These recommendations, representing the best accepted safety practices at the time when made, are given in table 8.

TABLE 8. - Recommendations for preventing Virginia explosions made at time of explosions

Recommendations	Times made
Inspection for gas and ventilation of mine or section before men enter	19
Ventilation, improve or adopt proper system	17
Supervision	9
Use of permissible closed lights in place of open lights	9
Use of flame safety lamps in place of open lights	7
Dust control (watering, dust removal, rock dusting)	8
Safer blasting (eliminate overcharged holes, coal-dust stemming, solid shooting)	4
Permissible explosives and blasting methods	3
Safer storage of black blasting powder	1

Inspection.- Failure to inspect for gas and to clear it from workings before allowing men to entor were primary factors in 19 of the explosions listed in table 2. Safety inspections, including rigid search for explosive gas, should be regularly and thoroughly made before shifts enter and at such intervals afterward as conditions may require.

Ventilation. Natural ventilation or the circulation induced through two openings or compartments in the same opening by differences of elevation or the movement of buckets or skips, or otherwise, was the chief method of ventilation for many years. Furnaces or small blowing engines were installed to help out when more air had to be provided; later fans became common equipment. In 1914, of 102 mines inspected by the State department, 95 had fans; in 1920, 217 fans were reported in 247 mines inspected. At present it is probable that nearly all mines of any size are so equipped, although in some instances the efficiency of the control of the air may be rather low. Several important mines in Virginia have revamped their ventilating systems within the past year to obtain adequate, controlled, and more economical ventilation.

The recommendation to improve ventilation was made in 17 cases, including one in which gas was not involved, where lack of circulation of air allowed fumes and fine dust from blasting to form dangerous mixtures in the air and contributed to a dust explosion ignited by blasting.

Supervision.- Failure to exercise adequate supervision was a factor in at least 9 cases; it was the direct cause of the conditions causing some of the explosions and an indirect cause of others through failure to see that firebosses or other responsible officials were competent and diligent in performing their duties or to guard against carrying open lights into gassy workings.

The direct cause of an explosion often may be an act or accident for which those charged with supervision of the mine are not directly responsible; but they are very likely to be responsible for the conditions in the mine which permit the initiation or propagation of an explosion.

Flame safety lamps and permissible closed lights.- The Davy or the Clanny flame safety lamp was available before the earliest occurrences listed; although they gave poor light their use, at least in inspection and in workings where good ventilation was not assured, would have prevented many of the early explosions. Effective, relatively safe, closed lights were used in near-by coal-mining districts before 1910. In 1919 an installation of 125 permissible electric cap lamps was made in the Southwest field and in 1920 a second; in 1932 approximately 3,900 were in use, and this number was increased to 4,820 by the summer of 1933.

Nine explosions were caused by open lights in Virginia after practical electric cap lamps had been in use in coal mines in the United States. Twenty-eight of the ignitions listed in table 2 were caused by open lights in mines since 1910; the Bureau of Mines recommends the use of electric cap lamps of permissible type in all coal mines as a measure of safety, efficiency, and economy.

Dust control.- In 1932, 18 explosions occurred in bituminous mines in the United States. In at least 4 of these mines rock-dust localized the explosion and saved 100 to 300 lives; in 2 other mines only partly protected by rock-dusting the explosion spread to untreated workings and caused the death of 15 or 20 men.

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From 1839 to the time rock-dust was proved and widely used as a protective measure, in at least 6 cases in Virginia the use of water to allay the dust and the removal of accumulations of fine coal and dust very probably would have prevented or greatly reduced the force and loss of life from explosions; in 1 instance the use of these measures did limit the spread of the explosion in a mine where several previous disasters had demonstrated the need.

As nearly as could be ascertained, only 1 mine in the State was using rock-dust before 1932. This mine was in the Southwest area. In 1932 two explosions in Virginia cost 48 lives in mines that could have been protected with rock-dust, and it is very probable that if they had been so protected few if any of the 48 lives would have been lost. Since then the mines of the Pocahontas field have been rock-dusted, and at least 3 others in the Southwest Virginia field have adopted it to some extent. Treatment of several others is understood to be under consideration.

As shown in table 9 the dust of the Richmond Basin coals was and is decidedly explosive, requiring 55 to 65 percent of incombustible matter to prevent propagation of an explosion.

No proof is needed of the explosive qualities of dust from the Pocahontas coals after actual experience. Tests in the Experimental mine on coal dust from Pocahontas no. 3 bed show that an average of 57 percent of incombustible content is necessary to prevent propagation.

The semianthracites of Pulaski and Montgomery Counties are on the border line between nonexplosive and possible explosive rank. Tests in the Experimental mine of the Bureau of Mines show that with 1 percent to 2 percent of methane in the air an explosion may be propagated by the dust of these coals.

The analyses of several beds in the Southwest field are given with their volatile ratios and the indicated percentages of incombustible material needed to prevent propagation of an explosion. This percentage ranges from 55 to 61, depending on the fineness of the dust, no gas being present.

Years of experience, full-scale tests, and studies of actual practice have caused the Bureau of Mines to recommend rock-dusting of coal mines as expressed in Mine Safety Board Decision 5.[7]

Explosives and blasting.- Permissible explosives were developed and their use advocated as a safety measure long before 1915. There were 4 explosions before that time in which use of excessive charges of black blasting powder, solid shooting, coal-dust tamping instead of clay, or firing dynamite in an open charge were the causes. In one instance gas was ignited by a match employed to light fuse, although electric cap lamps were used; this combination is by no means uncommon, although it is neither necessary nor safe.

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[7] See page 21, or Recommendations of the U. S. Bureau of Mines on Certain Questions of Safety: Bureau of Mines Inf. Circ. 6732, July 1933, 43 pp.

TABLE 9. - Analyses of Virginia coals

Content	Richmond Basin1/, average percent	Pocahontas no. 3 bed2/, average percent	Semianthracite							
			Merimac bed			Southwest Virginia field				
			Montgomery County, percent		Pulaski County, percent	Upper Banner, percent	Dorchester, percent	Imboden, percent	Taggart, percent	Pardee, percent
Moisture	2.0	1.7	3.6	1.4	1.0	2.8	2.6	2.4	2.0	2.8
Volatile matter	29.0	22.0	9.5	9.0	11.4	32.7	34.0	34.3	34.9	35.3
Fixed carbon	60.0	69.6	67.6	72.6	55.7	57.9	58.0	57.8	60.9	55.7
Ash	9.0	6.7	19.3	17.0	31.9	6.6	5.4	5.5	2.2	6.2
Volatile ratio	.33	.24	.12	.11	.17	.36	.37	.37	.37	.39
Indicated incombustible needed	61.0	57-58	20.0	-	40.03/	55 to 61				

1/ Virginia Geological Survey Bull. 29, p. 108.
2/ Experimental mine tests.
3/ Indicated incombustible needed by Bureau of Mines tests with 1 percent of gas.

After permissible explosives were readily available and in more or less general use 2 explosions in Virginia were caused by the use of other than permissible explosives and permissible shooting methods.

Table 10 shows the amount of explosives of various types used in Virginia for certain years, as reported to the office of the State mine inspector.

TABLE 10. - Explosives used in Virginia coal mines

Year	Black blasting powder, percent	Dynamite, percent	Permissible, percent	Year	Black blasting powder, percent	Dynamite, percent	Permissible, percent
1913	83	13	4	1928	60	6	34
1914	78	9	13	1931	60	9	31
1920	80	5	15	1932	60	8	32
1924	67	8	25				

All forms of black blasting powder--granular, pellet, or stick--are grouped together in table 10. Until late years nearly all black blasting powder was in granular form, sold in kegs, but has been largely replaced by pellet and stick varieties. From an explosion standpoint, the hazards are essentially the same. The dynamite used is virtually entirely for shooting top rock, although types of permissible explosives are available to do this work and do it well. It is notable that there has been no appreciable change in the percentages of the various kinds of explosives used in Virginia coal mines since 1928. The hazards of shooting with nonpermissible explosives are well known, but settled practices are usually changed only when a catastrophe focuses attention on an existing hazard.

As late as 1918 an explosion was caused by shooting from the solid with black blasting powder; this practice is gradually being abandoned but has not yet been eliminated. The figures given below indicate the trend as reported by the State inspector and as given by Bureau of Mines records.

TABLE 11. - Percentage of total production machine-mined in Virginia

Year	Percent	Year	Percent
1897	20	1915	63
1900	10	1920	70
1903	2	1925	82
1907	17	1930	86
1910	35	1931	86

These figures include both the semianthracite and bituminous production. None of the semianthracite is machine-mined, but all is shot with permissible explosives. In 1931, 88 percent of the bituminous coal was mined by machine, less than 3 percent was mined by hand, and over 9 percent was shot off the solid. In the anthracite field 22 percent was shot off the solid.

Attention is called to the following decisions of the Mine Safety Board[8] of the United States Bureau of Mines, which refer to conditions described in this paper:

Decision 1, relating to miner's lamps in coal mines

The United States Bureau of Mines recommends:

1. In all coal mines the portable lamps for illumination be permissible, portable, electric mine lamps; and also
2. In places where fire damp or black damp is liable to be encountered, a permissible, magnetically locked, flame safety lamp for gas detection, or equivalent permissible device, be supplied to at least one experienced employee in each such place; and
3. Any employee before being supplied with a permissible flame safety lamp be examined by a competent official of the mine to assure the man's ability to detect gas; and
4. All coal mines whether classed as nongassy or gassy in any part, be supplied with magnetically locked, permissible, flame safety lamps, properly maintained and in sufficient number for all inspection purposes.

Decision 2, relating to the kind of explosives to use in coal mining

In the interest of safety the United States Bureau of Mines recommends that for blasting in coal mines, permissible explosives, fired electrically, be exclusively used; and that as an aid to blasting, all coal which is feasible to cut, should be cut or sheared.

Decision 3, defining what the Mine Safety Board considers to constitute a nongassy, a slightly gassy, and a gassy coal mine

The United States Bureau of Mines believes that all coal mines are potentially gassy; but for purposes of administration in respect to prevention of explosions and fires, the Bureau recommends the following classification:

Class 1 Coal Mine: A practically nongassy mine in which inflammable gas in excess of 0.05 percent cannot be found by systematic search.

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[8] See footnote 7.

Class 2 Coal Mine: A slightly gassy mine in which -

(a) Inflammable gas has been found* but in amount less than 2 percent in still air in any active or unsealed abandoned workings; or

(b) Inflammable gas can be found, but in amount less than 4 percent, in some place from which the ventilating current has been shut off for a period of 1 hour; or

(c) Inflammable gas can be found** but in amount less than $\frac{1}{4}$ percent, in a split*** of the ventilating current; or

(d) Inflammable gas enters a split*** of ventilating current at a rate**** of not more than 25 cubic feet per minute.

Class 3 Coal Mine: A gassy mine in which inflammable gas is found in amount greater than specified for a class 2 coal mine.

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* By employing an approved flame safety lamp, with flame drawn low, or by employing an approved gas detector, or by sampling and analysis with an approved gas analytical apparatus.

** By sampling and analysis with an approved gas analytical apparatus, or by employing an approved gas detector.

*** If but one continuous ventilating current is employed in a mine this shall be considered a "split" for the purpose of this definition.

**** Determined by sampling, analysis, and ventilating-current measurement.

Decision 4, relating to auxiliary fans or blowers in coal mines and coursing of air

In the interest of safety, the United States Bureau of Mines, recommends that auxiliary fans or blowers should not be used in coal mines as a substitute for methods of regular and continuous coursing of the air to every face of the mine.

Decision 5, relating to the prevention of coal-dust explosions by rock-dusting.

To prevent the propagation of mine explosions, the United States Bureau of Mines, recommends rock-dusting all coal mines, except anthracite mines, in every part, whether in damp or dry condition. It also recommends that rock-dust barriers be used to sectionalize the mine as additional defense; but these should not be regarded as a substitute for generalized rock-dusting.

Decision 6, relating to sealing all parts of a coal mine which cannot be kept well ventilated and inspected

In the interest of safety, the United States Bureau of Mines recommends that in coal mines all entries, rooms, panels, or sections that cannot be kept well ventilated throughout or cannot be inspected regularly and thoroughly, or that are not being used for coursing the air, travel, haulage, or the extraction of coal, be sealed by strong fireproof stoppings.

Decision 7, relating to the carrying of "intake" and "return" air currents in separate shafts, slopes, or drifts

In the interest of safety, the United States Bureau of Mines recommends:

1. That the main intake and main return air currents in mines be in separate shafts, slopes, or drifts.
2. That the main intake shaft lining be of fireproof construction and there be a minimum amount of inflammable material in or adjacent to the shaft.

Decision 9, relating to the quantity and quality of air to be furnished in ventilating mines

The United States Bureau of Mines recommends in coal-mine ventilation practice the following specifications as to unit quantity and quality of air:

1. The quantity in cubic feet of pure intake air flowing per minute in any ventilating split shall be at least equal to 100 times the number of men in that split.
2. The quantity of air entering each unsealed place shall be at least 200 cubic feet per minute and as much more as may be necessary properly to dilute and carry away inflammable or harmful gases which may be present.
3. The air shall be made to circulate continuously to the face in every unsealed place into which an appreciable amount of methane enters.
4. The air in any unsealed place shall be considered unfit for men if it shall be found to contain less than 19 percent oxygen (dry basis), more than 1 percent carbon dioxide or a harmful amount of poisonous gas.
5. If the air in any unsealed place, when sampled or tested in any part of that place not nearer than 4 feet from the face and 10 inches from the roof, shall be found to contain -
    (a) More than $1\frac{1}{2}$ percent of inflammable gas, the place shall be considered to be in hazardous condition and require improved ventilation, and
    (b) If more than $2\frac{1}{2}$ percent of inflammable gas is found, the place shall be considered dangerous, and only men who have been officially designated to improve the ventilation and are properly protected shall remain in or enter said place.

6. If the air in the split which ventilates any group of workings contains more than $1\frac{1}{2}$ percent of inflammable gas, these workings shall be considered to be in a dangerous condition and only men who have been officially designated to improve the ventilation and are properly protected shall remain in or enter said workings.

Decision 11, relating to haulage and hoisting in coal mines with reference to the ventilation

In the interest of safoty, the United States Bureau of Mines, recommends that in coal mines, haulage and (or) hoisting be kept in intake air as far as possible.

Decision 12, relating to methods of firing shots in coal mines

The United States Bureau of Mines extending Mine Safety Decision 2, recommends that for blasting either coal or rock in coal mines, permissible explosives or equivalent permissible device be used exclusively, and in addition recommends that in blasting -

1. Each charge shall be in a hole properly drilled and stemmed with incombustible material.
2. Each shot shall be fired separately by a permissible single-shot blasting unit, using an electric detonator or igniting equivalent of a kind specified by the Bureau for the particular permissible explosive or permissible blasting device.
3. Before and following each shot in gassy and slightly gassy coal mines, examination for gas shall be made with a permissible flame safety lamp or permissible equivalent and -
4. If more than $1\frac{1}{2}$ percent of inflammable gas is found, in the quantity and by the method specified in Mine Safety Decision 9, the place shall be considered to be in a hazardous condition and before another shot is fired the gas shall be reduced by ventilation below the percentage and quantity specified in decision 9.
5. Each shot employing explosives shall be prepared and fired by or under the immediate supervision of a man having a state certificate as a mine examiner, fire boss, or foreman; and whenever conditions permit all other men than those authorized to prepare and fire shots shall be out of the mine when shot firing with explosives is being done.

Decision 13, relating to electrical equipment in coal mines which may become gassy

The United States Bureau of Mines recommends that when electricity is used in coal mines rated as gassy, or whenever in any mine the atmosphere may become gassy:

1. Electrical equipment shall be permissible,
2. Nonpermissible electrical equipment*** shall be used only in pure intake air,
3. Electrical power shall be cut off whenever the air in the workings is in a dangerous condition, due to inflammable gas.

Decision 15, wetting machine cuttings, the face, and tops of cars in coal mining

In the interest of safety in coal mining, the United States Bureau of Mines to lessen the coal-dust explosion hazard recommends that:

1. Machine coal cuttings be wet as the cutting is being done.
2. The coal face, and the working place 40 feet therefrom, shall be kept free of coal-dust by the use of water.
3. The top of loaded cars in the working place shall be wet.

Decision 16, machine cuttings to be removed in coal mining

In the interest of safety in coal mining, the United States Bureau of Mines recommends that:

1. Machine cuttings be removed from the cut.
2. If the machine cuttings are of a character which would contribute to a dust explosion, they shall be sent out of the mine.

Decision 17, lessening the formation and distribution of coal-dust in haulageways in coal mines

To lessen the formation and distribution of coal-dust in haulage-ways, the United States Bureau of Mines, recommends that in bituminous and lignite coal mines:

1. The mine cars should be constructed and maintained dust-tight.
2. The coal should be so loaded that it will not shake off in haulage.
3. The cars and loads should be so sprayed as to prevent dust being distributed along the haulageways.

Decision 18, superintendents and foremen of coal mines should have State certificates of competency

In the interest of safety in coal mining, the United States Bureau of Mines recommends that:

1. The foreman regularly in charge of underground operations and also any person who, in the absence of the foreman, may be placed in temporary charge should each have a certificate of competency from the State to act as mine foreman.

2. The superintendent or person in responsible charge of the mine, to whom the mine foreman reports, should have a certificate of competency from the State which should be issued upon a showing of underground experience for a period of time as long as that required for a foreman's certificate and upon passing an examination including all technical questions asked in the examination required of foremen.

3. These certificates should expire after some stated period of time, such as 5 years, and should be renewed only after the applicant has again passed the examination required by the State.

CONCLUSIONS

Dust of the semianthracites has been found to be explosive in the presence of gas by both experience and tests made in the Experimental mine to determine limiting conditions. The dust of coals of southwest Virginia is by analysis clearly within the explosive range, and this has been shown by explosions propagated by dust in several mines.

Although the mines in the Pocahontas field had worked 25 years without an explosion, later experience proved that explosions can and will occur unless reasonable precautionary measures are taken, and now it should be evident that the best protection against widespread propagation of an explosion can be afforded only by adequate rock-dusting supplementing other safety features, such as effective ventilation, adequate supervision, and the use of up-to-date and readily available safe methods and equipment. The information necessary for proper application of rock-dust to these mines was obtained by means of large-scale tests conducted in the Experimental mine of the United States Bureau of Mines at Bruceton, Pa., using dust from these coals.